National Aeronautics and
Space Administration

Washington, D.C.
20546

NOV 1 9 1993

Reply to Attn of: SZG

TO: Distribution

FROM: S/Associate Administrator for Space Science

SUBJECT: Hubble Space Telescope First Servicing Mission
Prelaunch Mission Operation Report

The first mission to service the Hubble Space Telescope (HST), designated STS-61 and using Orbiter Endeavour, will be launched during a window that begins on December 1, 1993. The purpose of this mission is to restore the Space Telescope's scientific and engineering capabilities through servicing by astronauts during Extra Vehicular Activities (EVA). It will also verify that satellite on-orbit servicing is a feasible method of achieving Hubble's 15-year lifetime.

The enclosed Mission Operation Report: (a) describes the objectives of this first servicing mission; (b) describes the sequence of mission activities that will be followed to service, deploy, and operationally verify the HST; (c) outlines the ground operations elements required to support this mission; and (d) provides summary cost information for the HST program to date and of the First Servcing Mission in particular.

Wesley T. Huntress, Jr.

Wesley T. Huntress, Jr.

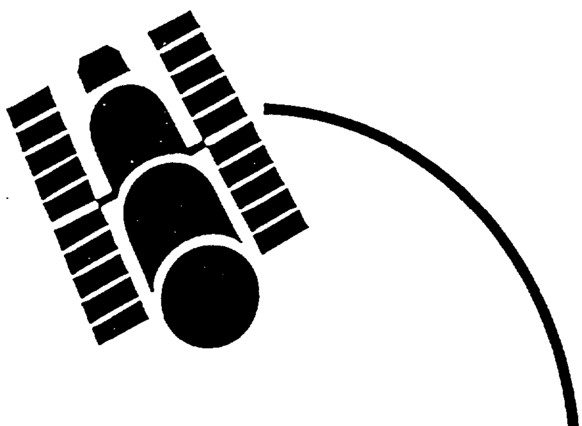
Enclosure

National Aeronautics and
Space Administration

Pre Launch
Mission Operation Report

OFFICE OF SPACE SCIENCE

Report No.S 458-61-93-02



HUBBLE SPACE TELESCOPE

Hubble Space Telescope—First Servicing Mission

November 1993

Table of Contents

FOREWORD

MISSION OPERATION REPORTS are published expressly for the use of NASA senior management. The purpose of these reports is to provide NASA senior management with timely, complete, and definitive information on flight mission plans, and to establish official mission objectives which provide the basis for assessment of mission accomplishments.

Reports are prepared and issued for each flight project just prior to launch. Following launch, updated reports for each mission are issued to keep management currently informed of definitive mission results as provided in NASA Headquarters Management Instruction (HQ MI) 8610.1C.

These reports are sometimes highly technical and are for personnel having program/project management responsibilities. The Public Affairs Division publishes a comprehensive series of reports on NASA flight missions which are available for dissemination to the news media.

GENERAL

The Hubble Space Telescope (HST) is a high-performance astronomical telescope system designed to operate in low-Earth orbit. It is approximately 43 feet long, with a diameter of 10 feet at the forward end and 14 feet at the aft end. Weight at launch was approximately 25,000 pounds. In principle, it is no different than the reflecting telescopes in ground-based astronomical observatories. Like ground-based telescopes, the HST was designed as a general-purpose instrument, capable of using a wide variety of scientific instruments at its focal plane. This multi-purpose characteristic allows the HST to be used as a national facility, capable of supporting the astronomical needs of an international user community. The telescope's planned useful operational lifetime is 15 years, during which it will make observations in the ultraviolet, visible, and infrared portions of the spectrum. The extended operational life of the HST is possible by using the capabilities of the Space Transportation System to periodically visit the HST on-orbit to replace failed or degraded components, install instruments with improved capabilities, re-boost the HST to higher altitudes compensating for gravitational effects, and to bring the HST back to Earth when the mission is terminated.

The largest ground-based observatories, such as the 200-inch aperture Hale telescope at Palomar Mountain, California, can recognize detail in individual galaxies several billion light years away. However, like all earthbound devices, the Hale telescope is limited because of the blurring effect of the Earth's atmosphere. Further, the wavelength region observable from the Earth's surface is limited by the atmosphere to the visible part of the spectrum. The very important ultraviolet portion of the spectrum is lost. The HST uses a 2.4-meter reflective optics system designed to capture data over a wavelength region that reaches far into the ultraviolet and infrared portions of the spectrum.

The scientific objectives of the HST are to determine the constitution, physical characteristics, and dynamics of celestial bodies; the nature of processes that occur in stellar objects; the history and evolution of the universe; and whether the laws of nature are universal in the space-time continuum.

The HST was developed by NASA under the direction and supervision of the Astrophysics Division of the Office of Space Science at NASA Headquarters. The Marshall Space Flight Center in Huntsville, Alabama, was responsible for the design, development, fabrication, and assembly of the telescope. It also conducted orbital verification of the observatory's systems after launch. Project management for the HST was transferred to the Goddard Space Flight Center (GSFC) in Greenbelt, Maryland, about the time the orbital verification phase was nearing conclusion. Prior to the 1990 launch, GSFC was responsible for the development of four of the scientific instruments and the development of the HST ground-data system, which included management and oversight of the Space Science Telescope Institute in Baltimore, Maryland. The European Space Agency (ESA) played a significant role in development of the telescope by providing the electrical power-producing solar arrays and the Faint Object Camera instrument.

The Johnson Space Center in Houston, Texas, is in charge of the Space Shuttle mission operations phase of any servicing mission. It supplies the Shuttle and all Shuttle-associated hardware and trains astronaut crews to rendezvous with the HST and to repair and/or replace instruments and spacecraft hardware. The Kennedy Space Center in Florida readies the Shuttle Orbiter for launch, supervises the placement of the HST payload elements into the STS Cargo Bay, and provides launch services for the Shuttle.

The HST was launched on April 24, 1990, and, after a long period of orbital-systems checkout and calibration, began taking scientific observations. However, shortly after launch, two distinct phenomenon were discovered that caused degradation of the observed scientific data. First, it was discovered that the HST primary mirror exhibited spherical aberration. This flaw prevented light from being focused at a single point, denying the scientific observers the total clarity and scientific detail they were seeking. The second problem involved the power-producing solar arrays. When passing into and out of the orbital shadow, thermal expansion and contraction from heating and cooling of the arrays caused them to undergo a transient distortion, which induced a jitter strong enough for the HST's pointing and control system to lose lock on the target stars.

Prior to the HST launch, a planned servicing mission was scheduled for 1993 to install an updated Wide Field and Planetary Camera (WFPC2). Since launch, other anomalies have occurred. Consequently, NASA established other requirements for on-orbit repair or replacement during this first servicing mission. These anomalies include two rate gyro failures along with two rate gyro electronics control units, loss of some memory in the HST's main DF-224 computer, magnetometer fluctuations, reduced use of the Goddard High Resolution Spectrograph, a solar array drive electronics failure. Thus, the planned first servicing mission has been structured to repair these anomalies and restore the HST to a fully operational vehicle.

The WFPC2 was redesigned by the Jet Propulsion Laboratory. It now includes new cameras, with charged coupled device detectors, and corrective optics to compensate for the HST primary mirror flaw. Another set of corrective optics, to better focus the light sources for the other scientific instruments, was assembled by Ball Electro-Optics and Cryogenics Division. This package, called the Corrective Optics Space Telescope Axial Replacement (COSTAR), will enhance the HST's performance by providing corrective optics for the Faint Object Camera, Faint Object Spectrometer and Goddard High Resolution Spectrograph.

The HST is currently in a 317-nautical-mile circular orbit. At that altitude, free of atmospheric distortion and absorption, the telescope can provide a resolution approximately five to 10 times better than that obtainable with the largest telescopes on Earth. Even with the spherical aberration effect, objects at five to 10 billion light-years, for example, are seen by the HST with as much detail as objects at one billion light years are now seen with earthbound telescopes. With the optical correction in place, this resolving power will be augmented by the renewed ability to image very faint objects and to distinguish individual objects in crowded fields.

For other servicing tasks, an improved solar array system has been developed by ESA and is designed to reduce the transitional jitter to acceptable levels. Replacement gyros and associated electronics packages, a redundancy kit for the GHRS, an upgraded solar array drive electronics package, and a new set of magnetometers have been readied for launch. Also, a co-processor has been developed to expand the memory capability of the spacecraft DF-224 main computer.

A very ambitious and highly complex first servicing mission has been planned. This mission is scheduled for flight on December 1, 1993.

MISSION OBJECTIVES

Space Shuttle mission STS-61 is designed to rendezvous with and service the on-orbit Hubble Space Telescope. This will be the first of several planned servicing missions for HST, intended to periodically replace failed components and upgrade scientific instruments with improved versions so as to keep the telescope a viable and productive national resource throughout its planned 15-year lifetime. This First Servicing Mission is also intended to correct several design flaws that were detected shortly after the launch of HST. There are three overall mission objectives:

- **To Restore the Planned Scientific Capabilities**

One unforeseen complexity of the First Servicing Mission is the necessity for adding optical elements in the light path to correct for the spherical aberration on the primary mirror. These corrective optics are required to provide the quantitative science capability that will enable key programs to be carried out as originally planned. This includes gaining the ability to separately analyze objects in crowded fields and to reach very faint objects, especially those located at the far edge of the universe. Several of the questions Hubble was designed to answer have not been addressed because of the spherical aberration. Both the addition of COSTAR and the installation of WFPC2 will independently contribute to recovering these capabilities.

- **To Restore the Reliability of Vehicle Systems**

The Hubble spacecraft was designed with sufficient subsystem redundancy to enable it to remain safe and continue science operation in the event of likely component anomalies. This design has proven resilient, as today Hubble continues to collect outstanding science data despite anomalies from failed or degraded components. However, this has depleted some of the original redundancy which must be restored to allow continued science operations until the next servicing mission. By re-establishing redundancy, this first mission will restore the reliability of vehicle systems. Anomalous components slated for service include the solar arrays, gyroscope sensing units, gyroscope electronics, magnetometers, solar array drive electronics, and electrical fuses.

- **To Validate the On-Orbit Servicing Concept for HST**

The concept of an Earth-orbiting spacecraft constructed to be maintained for a 15-year mission through regularly scheduled, manned servicing visits is relatively new. Although HST was designed and built with orbital replacement units, grapple fixtures and astronaut handholds to make servicing easier, this First Servicing Mission is particularly challenging because of the additional tasks to correct design flaws. This first mission will validate the concept of on-orbit servicing as the way to achieve HST's full 15-year life, providing a foundation for future servicing missions.

The complex nature of this mission and the number of challenging tasks to perform may make it difficult to accomplish all planned tasks during the STS-61 flight. Depending on the status of HST and the servicing hardware after the flight, a contingency backup Shuttle mission may be scheduled to complete objectives not achieved on STS-61.

Mission Success Criteria

Given the expressed objectives and the fact that the First Servicing Mission will be a newly attempted, complicated set of tasks, it is relevant to consider what must be achieved to constitute mission success. Success, however, can be measured at several levels. At the top level, we must:

1) Avoid risk to the flight crew, the shuttle and the telescope
2) Maximize the probability that all **primary** servicing tasks are done
3) Leave HST in the best operational state possible after the STS flight

To achieve the highest state of HST operational capability, the STS-61 mission planning strategy has been to prepare for servicing options that accomplish more than the required primary servicing tasks and to take along the associated HST flight hardware. All servicing tasks will be prioritized and planned for accomplishment in priority order, consistent with timeline and shuttle servicing constraints. Lower priority items will be achieved on a best-efforts, time-available basis. If servicing activities are completed faster than planned, the extra time available can be used for lower priority tasks. Appropriate flight rules will be developed to govern the re-scheduling of tasks in real-time as necessary to respond to changing in-flight situations.

With these considerations in mind, the accomplishments necessary to minimally satisfy the overall mission objectives are those which will leave HST with:

- **at least 3 reliable (newer design) gyro systems, and,**
- **either an operational WFPC2 or COSTAR.**

This level of accomplishment will correct the optics for part of the science instrument complement, will restore the most critical vehicle redundancy, and will demonstrate on-orbit servicing. This provides a reasonable probability that the telescope will continue to carry out some of the key programs until another shuttle flight can be launched. Installing either WFPC2 or COSTAR will allow re-arrangement of the science schedule so that HST can be fully utilized prior to the backup mission to perform some of the backlogged quantitative science programs using corrected optics.

In order to be considered **fully** successful, the primary list of servicing tasks must be accomplished. If they are not completed during the STS-61 mission, a backup mission will be requested. The timing for the backup mission is dependent on the payload item(s) not achieved and why they were not achieved. This primary list consists of:

PRIMARY SERVICING TASK LIST:

- Solar Array II
- Gyro Pair #2
- WFPC2 and instrument fuses
- COSTAR
- Magnetometer System #1
- Gyro Pair #3 (with electronics unit #3)
- Solar Array Drive Electronics #1

The prominent position of the replacement solar arrays on the priority list assumes that the solar array I blankets will be retracted into their cassettes. If for any reason, they are not retracted, but servicing instead is conducted with solar array I still deployed, solar array II installation will no longer be considered a primary servicing task. This is the reason solar array replacement does not appear in the minimum success criteria scenario. It should also be noted that on-board gyro pair #1 consists of the newer design gyro units, such that replacement of either pair #2 or pair #3 would satisfy the minimum success criteria.

Although preliminary planning for a contingent backup servicing mission may be done, the plans will not be activated before the completion of the STS-61 mission because the time frame for the re-flight is heavily dependent on which of the seven tasks remains to be accomplished. (For example, gyros could be re-flown within five months, but if WFPC2 needs to be disassembled due to atmospheric contamination on re-entry, it might require at least nine months to purge, clean and re-certify for flight.)

The completion of the entire primary servicing task list provides the best chance of maintaining HST quantitative science operations until the next scheduled servicing mission. The remaining items on the manifest are for secondary servicing tasks that will be done as time permits. This list consists of the GHRS redundancy kit, the DF-224's 386 co-processor, magnetometer system #2, gyro fuse plugs, and the electronics control unit for gyro pair #1. Although accomplishment of these items would provide additional HST system redundancy and enhanced operational capability, they are not considered essential for mission success (based on the current state of the HST vehicle) and would be deferred until the next servicing mission, currently scheduled for 1997, if they were not completed on STS-61.

HST Success

While the success of STS-61 will be judged, in part, on what servicing tasks are accomplished, which can be assessed after release of HST from Endeavour, the success of the servicing to the scientific capabilities of the observatory must await the on-board verification of the flight equipment serviced. Some of the equipment (such as gyros) can be functionally verified shortly after release from the Orbiter, however, the functioning of WFPC2 and COSTAR must wait until optics deployment, calibration, alignment, and focusing are completed. The current observatory verification timeline indicates the first corrected images are expected about seven weeks after HST re-deployment while full verification of all optical paths may require up to 16 weeks.

Finally, the success of the Hubble Space Telescope, as a scientific program, must be judged on its overall performance over its planned 15-year lifetime, of which the first servicing mission is one significant milestone.

Kenneth W. Ledbetter
HST Program Manager

Edward J. Weiler
HST Program Scientist

Arthur J. Fuchs
Chief, Observatories Development Branch

for G.N.
George P. Newton
Acting Director, Astrophysics Division

Wesley T. Huntress, Jr.
Associate Administrator for Space Science

MISSION DESCRIPTION

The first HST Servicing Mission (STS-61), using the Space Shuttle Orbiter Endeavour, will be launched from the Kennedy Space Center at approximately 4:57 AM EST on December 1, 1993. There is a 71-minute launch window which is governed by rendezvous and lighting constraints at the Trans-Atlantic Landing sites and by end-of-mission landing considerations. If for some reason the launch day slips, the opening of the launch window will be about 30 minutes earlier on each successive day.

The Orbiter will fly a direct-insertion trajectory into approximately a 315-nautical-mile circular orbit with an orbital inclination of 28.45 degrees and an orbital period of about 95 minutes. The mission is scheduled for a duration of about 12 days. It will carry a crew of seven astronauts, with five planned Extra Vehicular Activity (EVA) days to accomplish the mission. Two additional EVA days are available if required for contingency operations.

Two EVA teams, consisting of two members each, will provide alternating support for each EVA day. The primary team will perform the first, third, and fifth EVAs, with the secondary team performing the second and fourth EVAs. Each EVA will last about six-hours. The EVA teams have been cross-trained for all servicing activities to accommodate any off-nominal situations.

On flight day (FD) one, payload space support equipment will be activated in the post-insertion timeframe. On FD2, the Orbiter's Remote Manipulator System (RMS) will be activated and checked out. On FD3, the Endeavour will rendezvous with, grapple, and berth the HST. FD4 through FD8 will nominally be occupied with the five servicing EVAs. If sufficient Orbiter propulsion propellant margins remain, the HST may be re-boosted to a higher orbit before the start of the fifth EVA. Nominal deployment of the HST will take place on FD9. FD10 is reserved as an unscheduled EVA/deploy day. Following the successful deployment of the HST, the payload space support equipment will be deactivated and stowed. The STS-61 mission also includes two additional on-orbit days in the event of adverse Orbiter landing weather conditions or equipment contingency delays prior to landing.

After the conclusion of the on-orbit servicing operations with the Orbiter, the HST will begin a several month period of Observatory Verification. This period will be used to verify the HST status, performance of all of the HST systems, and the alignment and calibration of the HST's scientific instruments.

MISSION SEQUENCE

Listed below are highlights of activities to be performed during the STS-61 mission. A graphic portrayal of the EVA timeline is included as figure 1.

Flight Day 1

Launch

Flight Day 2

The Orbiter Remote Manipulator System (RMS) will be activated and checked out. Shuttle support equipment will be tested and the Flight Support System (FSS) located in the Orbiter Payload Bay prepared for berthing. The HST will be maneuvered to the rendezvous attitude and its aperture door will be closed.

Flight Day 3

The Endeavour will rendezvous with the HST, and the Space Telescope Operations Control Center (STOCC) at GSFC will command the telescope to a sun-pointing inertial attitude. During rendezvous, the science instruments will be made safe and the high gain antennas retracted. When the range from Endeavour to HST is about 20 nautical miles, the Orbiter communications system will be used to provide STOCC support for HST telemetry and commanding. The flight crew will grapple the HST with the RMS and command the HST pointing and control system to a drift mode. The crew will then berth the HST on the FSS. Once secured on the FSS, an umbilical will be connected to the HST switching the observatory from internal power to Orbiter power. Endeavour will maneuver to position the HST solar arrays toward the sun to allow the batteries to recharge.

Flight Day 4/EVA Day 1

Once battery charging is complete, the astronauts will egress from the Orbiter. They will change out two rate sensing units, associated electronic control units and replace all fuse plugs. They will also prepare the solar arrays for change out on the next EVA day. After completion of the EVA activities, the solar arrays will be retracted in preparation for the next day's activities.

Flight Day 5/EVA Day 2

On Flight Day 5, the alternate EVA astronaut team will change out the solar arrays with the updated versions provided by ESA.

Flight Day 6/EVA Day 3

The WFPC1 will be replaced with WFPC2, and two new magnetometers will be installed.

Flight Day 7/EVA Day 4

On the fourth EVA day, the High Speed Photometer will be removed from the axial bay of the HST and replaced with the COSTAR. This will be followed by the installation of the DF224 's 386 co-processor.

Flight Day 8/EVA Day 5

If sufficient Orbiter propellant is available, the HST will be boosted to a higher altitude prior to the start of EVA Day 5. During this last scheduled EVA, the solar array drive electronics unit #1 will be replaced and the GHRS redundancy kit installed. The new solar arrays will be deployed while the EVA astronauts are in the payload bay so that they can assist with the deployment should any malfunction occur.

Flight Day 9

The HST will be configured for deployment from the Orbiter. Two consecutive orbits of battery charging will ensure the HST electrical power system is functional. The flight crew will use the RMS to grapple the HST, switch it back to internal power, release the electrical umbilical and the berthing latches, unberth the HST from the FSS, maneuver the HST to a release attitude and open the aperture door. The STOCC will verify systems integrity and give Johnson Spacecraft Center the "Go" for release. The flight crew will release the HST and perform two separation burns to back away from the HST. Immediately after release, the STOCC will command the HST into software sunpoint mode.

Flight Day 10

Flight Day 10 is currently reserved for an astronaut catch-up day or for any contingency work that may be required.

Flight Days 11 & 12

The crew of the Endeavour will stow the Orbiter cabin on Flight Day 11 and return to Earth on Flight Day 12 at the Kennedy Space Center.

Servicing Mission Orbital Verification (SMOV)

The SMOV phase of the mission will begin upon release from the Orbiter and will last until the initiation of normal operations by all scientific instruments. The SMOV program will verify that the components and instruments installed, replaced, or serviced on the HST Observatory are functioning properly. Alignment and calibration of the instruments using the upgraded optical capabilities will be accomplished.

During the first two weeks after release, the rate gyro assemblies and the fixed head star trackers will be aligned and calibrated. The Goddard High Resolution Spectrograph, Faint Object Camera, and Faint Object Spectrograph instruments will make baseline observations, and the COSTAR will deploy the optical benches for the Faint Object Camera and Faint Object Spectrograph instruments.

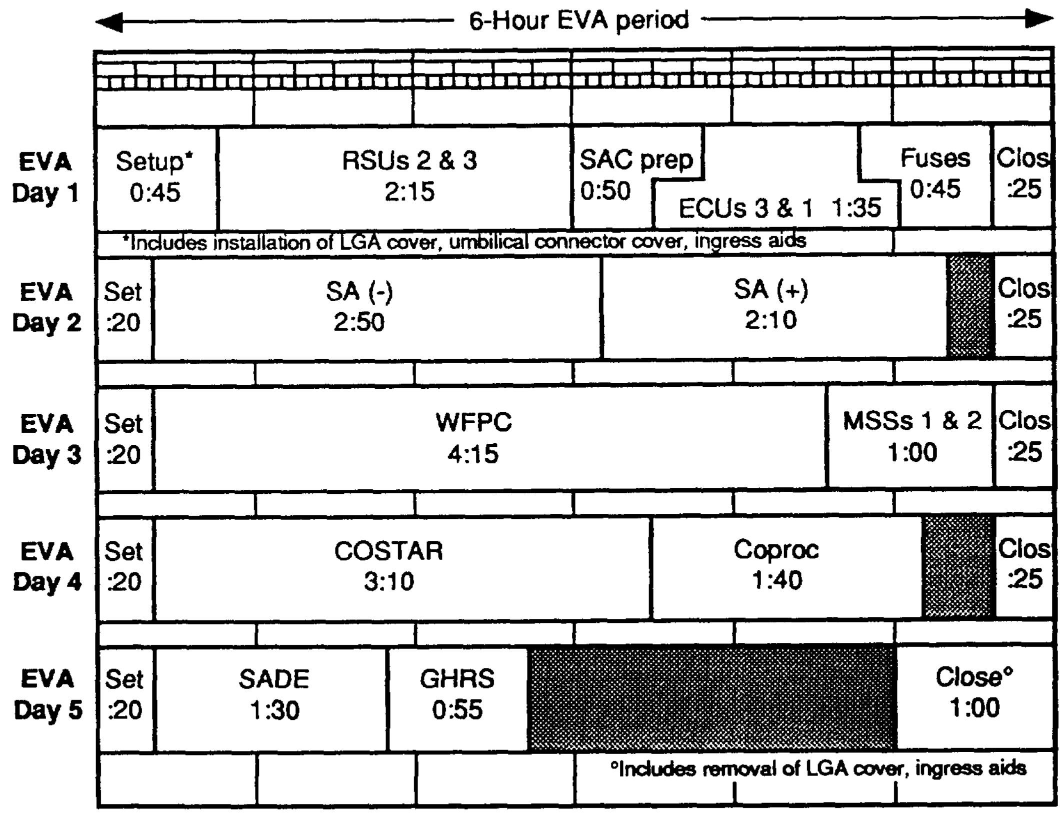
Two weeks after release, the WFPC2 will be checked out. It will be coarse-aligned for three weeks followed by two weeks of fine alignment and five weeks of science checkout, alignment, and calibration. About 14 weeks after release, the WFPC2 should be ready for science observations.

The FOC will begin coarse focus and alignment in the 4th week after release. Its checkout, fine alignment, and calibration should be finished at the end of the 13th week.

Also during the fourth week of SMOV, the FOS will go through its alignment and calibration program, finishing up at the end of the 13th week.

Meanwhile, the GHRS will be performing normal science observations with uncorrected optics from weeks two through seven. In the eighth week, the corrective optics for the GHRS will be deployed from COSTAR, at which time the GHRS will go through an alignment and calibration phase until the end of week 14.

Provided that SMOV goes smoothly, normal science operations with all instruments should begin during the 15th week after release from the Orbiter.



Priority Order	Task Times	Priority Order	Task Times
1. SA	0:50 (SAC)	6. RSU3	0:20 (2nd of 2)
	2:50 (1st wing)	ECU3	1:20 (1st ECU)
	5:00 (2 wings)	7. SADE	1:30
2. RSU2	1:55 (1st RSU)	8. GHRS Kit	0:55
3. WFPC	4:15	9. Coproc	1:40
P16 Fuses	0:10 (4 more plugs)	10. MSS2	0:10 (2nd of 2)
4. COSTAR	3:10	11. ECU1	0:15 (2nd of 2)
5. MSS1	0:50 (1st MSS)	P15 Fuses	0:35 (1st 4 plugs)

Setup: 0:45 (1st day), 0:20 (nth day)
Closeup: 0:25 (nth day), 1:00 (last day)

Figure 1: Scheduled EVA Timeline

PAYLOAD DESCRIPTION

The payload complement for the First Servicing Mission includes the orbital replacement unit carrier with a mission-specific complement of orbital replacement units and orbital replacement instruments, the solar array carrier with replacement solar arrays, and the GSFC flight support system to which the HST will be berthed for servicing. The replacement items for this First Servicing Mission will be used to correct the telescope's spherical aberration, to correct the jitter of the solar arrays, and to restore redundancy in instruments and spacecraft systems.

A new Wide Field and Planetary Camera and a corrective optics package will be installed into Hubble to correct for the spherical aberration of the primary mirror. The current solar arrays will be replaced by redesigned solar arrays. To restore redundancy, the HST will receive replacement gyroscope assemblies and associated electronics control units, new magnetometers, a new solar array drive electronics package, an improved computer co-processor, new fuses, and a GHRS redundancy kit. Each of these payload elements are described briefly in the following paragraphs, as are the flight carriers and support equipment.

Wide Field and Planetary Camera: The Jet Propulsion Laboratory team that built HST's original Wide Field Planetary Camera (WFPC1) began developing an upgraded instrument in 1985, which was planned as a replacement during the first servicing mission. The upgraded instrument, WFPC2, has new sensors that improves sensitivity, particularly in the ultraviolet portion of the spectrum. When the primary mirror flaw was discovered shortly after launch in 1990, NASA and the WFPC team immediately began work on an optical correction that could be built into WFPC2. The new design has a corrective prescription built into its optics and small actuators to fine tune the position of its internal mirrors to ensure their correct alignment. Through a servicing bay door built into the side of the HST, astronauts will slide out the 280-kilogram wedge-shaped WFPC1 and replace it with WFPC2.

Corrective Optics Space Telescope Axial Replacement (COSTAR): Built by the Ball Electro-Optics & Cryogenics Division under contract to NASA, COSTAR was defined by the HST Strategy Panel in the fall of 1990 to correct for the spherical aberration of the light entering HST's axial instruments. However, to install COSTAR, one of HST's four axial instruments must be removed. The HST team decided that COSTAR would displace the High Speed Photometer (HSP) because the photometer does proportionately less science than the other instruments. Astronauts will pull out the 220-kilogram,phone booth-sized HSP through a servicing bay door on the HST and install in its place the COSTAR package. COSTAR has no cameras or detectors. It uses precisely shaped mirrors to re-focus the light relayed from the flawed primary mirror before it enters HST's remaining three observing instruments: the Faint Object Camera, the Faint Object Spectrograph, and the Goddard High Resolution Spectrograph. COSTAR will deploy a set of mechanical arms (not much longer than a human hand) that will place corrective mirrors in front of the openings admitting light into those three instruments.

Solar Arrays: The replacement solar arrays are the original flight spare arrays which ESA has modified to eliminate the jitter problem. The modifications include the addition of thermal shields to reduce temperature gradients on the solar blankets' deployment booms and the redesign of boom length-compensation and blanket-tension mechanisms. When deployed, each solar array measures approximately 12x3 meters.

Gyroscopes: Three of HST's six gyroscopes have failed. While these failures have not affected HST's performance, no more redundancy remains. The HST has three rate sensor units (RSUs), each housing a pair of rate integrating gyros. Associated with each RSU is an electronics control unit (ECU) package which contains power supplies for each gyroscope. One gyroscope has failed in each of the three RSUs. Two RSUs and two ECUs will be replaced on this mission leaving HST with six new fully functional gyroscopes. Each RSU measures about 30x25x12 centimeters and weighs about 11 kilograms, and each ECU measures about 28x23x19 centimeters and weighs about 8 kilograms.

Magnetometers: The HST Magnetic Sensing System is comprised of two three-axis magnetometers. Both magnetometers have experienced intermittent anomalous behavior in one of their signal channels. The magnetometers are mounted forward on the HST light shield, near the observatory's aperture door. The new magnetometers have been built with brackets to be installed over the existing ones. Each magnetometer consists of a sensor unit which measures 11.7x7x7 centimeters and weighs 0.36 kilograms, and an electronics unit that measures 14.3x14.1x4.8 centimeters and weighs 0.73 kilograms.

Solar Array Drive Electronics: The solar array drive electronics (SADE) provide the command interface for slewing the solar arrays to the desired sun-pointing orientation. Two SADEs are provided for redundancy, one of which has failed. The flight spare SADE unit has been upgraded and readied for flight to replace the broken unit. The SADE unit measures about 35x15x23 centimeters and weights about 7 kilograms.

DF-224 Co-Processor: The DF-224 is the HST's main flight systems computer. Two of the computer's six memory units have failed. HST requires only three memory units to function fully, so the failures have not affected telescope operations. However, to restore the memory redundancy and augment the telescope's memory capacity, a co-processor (based on 386-computer architecture) has been developed and will be integrated with the flight systems computer. The co-processor measures approximately 18x38x20 centimeters and weighs about 10 kilograms. The flight-spare DF-224 computer also will be carried to orbit as a precautionary measure.

Fuses: The HST uses fuse plugs to protect its wiring harnesses and ORU equipment from short circuits. The servicing mission payload includes fuse plugs for two reasons. As originally planned, one type of each fuse plug will be available for contingency purposes. In addition, since HST's launch, it has been found that the fuse plugs protecting the gyro circuits need to be upgraded and the fuse plugs protecting the science instrument circuits needed to be replaced.

Goddard High Resolution Spectrometer Redundancy Kit: The Goddard High Resolution Spectrometer (GHRS) has two independent detector systems. The low-voltage power supply for the side-one detector had functioned erratically so that detector currently is not in use. All science operations have been conducted using the side-two detector. The GHRS redundancy kit consists of a relay box that will allow a commandable patch (cross-strapping) around the anomalous power supply. This will permit use of the side-one detector again. The relay box measures approximately 25x8x5 centimeters.

Orbital Replacement Unit Carrier: The Orbital Replacement Unit Carrier provides mounting accommodations and thermal conditioning for mission-unique orbital replacement units and orbital replacement instruments. The carrier provides load isolation for its complement of payload items. For this first servicing mission, the carrier is providing accommodations for the WFPC2, COSTAR, GHRS redundancy kit, RSUs, ECUs, co-processor, flight-spare DF-224, and magnetometers. The WFPC2 and

COSTAR are carried within the radial and axial Science Instrument Protective Enclosures respectively. The other equipment, with the exception of the magnetometers, are carried within two additional protective enclosures. The magnetometers and their holding brackets are mounted directly to the carrier.

Solar Array Carrier: The solar array carrier provides a platform on which the two HST replacement solar arrays will be transported to orbit. The old solar arrays, once removed from the HST, will be brought back to Earth on this carrier. The solar array carrier provides load isolation for the solar arrays, and it also carries the Contingency ORU Protective Enclosure, which contains the replacement solar array drive electronics and fuse plugs. The solar array carrier also supports an assortment of tools and crew aids for the astronaut servicing tasks.

Flight Support System: The GSFC-provided Flight Support System provides a stable platform for berthing, servicing, and positioning the HST.

Servicing/Support Equipment: HST has 49 different modular subsystems designed for servicing, ranging from small fuses to the scientific instruments. Also, HST features more than 10 meters of handrails and 31 footholds to aid EVA crews in servicing tasks. More than 218 tools, ranging from generic tools such as screwdrivers to special hardware designed specifically for HST servicing, are available for use on this mission. This equipment is carried in the three carriers mentioned above, in an HST tool box located in the orbiter payload bay, and on racks in the airlock.

MISSION SUPPORT

LAUNCH FACILITIES

The HST will be launched from Pad 39A on Space Transportation System Mission-61, following a four-month launch preparation period at the Kennedy Space Center.

TRACKING AND DATA ACQUISITION (DOWNLINK)

During normal operations, the Tracking and Data Relay Satellite System (TDRSS) is the primary interface between the HST and the Earth. Continuous multiple access return link capability and between 20 to 40 minutes per orbit of single access forward and return link capability has been allocated to the HST. The return link is used for the transmission of real-time telemetry, command verification, engineering and science tape recorder dumps, and ranging. Return link telemetry can be transmitted at 500 bps, 4 Kbps, 32 Kbps, or 1 Mbps.

The downlinked data is routed to the Data Capture Facility at GSFC via the TDRSS ground station at White Sands, New Mexico. From there, it is routed to the Space Telescope Operations Control Center (STOCC) at GSFC and then to the Space Telescope Science Institute (STScI) in Baltimore. The engineering data received is monitored at GSFC to ensure the health and safety of the HST. The science data is routed to the STScI where it is processed, calibrated, archived, and forwarded to the appropriate science investigators for analysis.

During the terminal phase of the Shuttle rendezvous and berthed portions of the STS-61 mission, HST telemetry will be via the Endeavour's telemetry and data system. The routing of the data will be from the HST to the Orbiter through TDRSS to the Johnson Space Center where the HST data will be stripped out of the data stream and forwarded to GSFC.

COMMAND (UPLINK)

Normal commanding of the HST is through the TDRSS. Stored program commands are included in the Service Mission Specification (SMS), which is uplinked weekly by the STOCC to the observatory. Also real-time commanding from the STOCC can augment the SMS loads or can be used in emergency commanding during safemode periods.

During the servicing mission, commanding of the HST from rendezvous through deployment will be from the STOCC to JSC to TDRSS to the Shuttle and then to HST. The STOCC transmits commands in coordination with the JSC operations personnel. A special two-step commanding sequence for hazardous commands has been established between GSFC and JSC to ensure that no unplanned commanding is attempted while the astronauts are performing work in the Orbiter payload bay. During servicing operations, the astronauts have the ability to send a limited number of commands to the HST from the Orbiter aft flight deck. These commands have been documented in the flight plan and in orbit operations checklists. Appendage movements, aliveness and functional testing of replaced or repaired hardware and instruments, and general houskeeping commands will originate at the STOCC. A detailed Command Plan covering all phases of the mission has been prepared, coordinated and tested. Commanding via SMS will not resume until after HST deployment and separation from the Orbiter and the HST's pointing and control system is aligned.

DATA FLOW

Before Orbiter rendezvous with the HST and shortly after deployment, the following data flow will be used. For HST observations, astronomers at the STScI decide about six weeks in advance where in the sky the HST should be pointed to make an observation. Target celestial coordinates are derived and transmitted via a microwave link to the GSFC STOCC. After processing at GSFC, the desired observations are melded into a SMS, which is uplinked to the HST each week via the TDRSS. Observations and housekeeping commands are executed by the SMS, recorded on-board, and transmitted from the HST over the reverse path to the STScI for processing, analysis, and archiving by the STScI and science observers.

FLIGHT DYNAMICS SUPPORT

The Mission Operations and Data Systems Directorate of the GSFC will provide support in the areas of mission analysis, orbit determination, and attitude determination for the HST. Shuttle flight dynamics will be performed via the normal JSC process.

HST OPERATIONS SUPPORT

The GSFC STOCC is the major facility for the scheduling and control of the HST. The STOCC represents the focal point for all mission operations, including HST command and control, determination of operations constraints and restrictions, HST health and status monitoring, and contingency actions relating to serious anomalies of the HST.

MISSION MANAGEMENT

The Office of Space Science (OSS), NASA Headquarters, is responsible for the overall direction and evaluation of the HST Program. The Associate Administrator for OSS has assigned Headquarters responsibility for this program to the Director of the Astrophysics Division. The GSFC has been assigned Project Management responsibility which includes responsibility for the development and operation of the HST science instruments, operation and maintenance of the HST ground data system (including oversight of the STScI in Baltimore, Maryland). The Office of Space Communications, NASA Headquarters, has overall tracking and data acquisition responsibility. The Office of Space Flight is responsible for the launch activities at the KSC as well as for the STS flight operations conducted by the JSC.

NASA Office of Space Science

Dr. Wesley T. Huntress, Jr.	Associate Administrator for Space Science
Alphonso V. Diaz	Deputy Associate Administrator for Space Science
Dr. George P. Newton	Acting Director, Astrophysics Division
Arthur J. Fuchs	Chief, Observatories Development Branch
Kenneth W. Ledbetter	HST Program Manager
George G. Albright	HST Program Manager for Operations
Dr. Edward J. Weiler	HST Program Scientist

NASA Office of Space Flight

Jeremiah W. Pearson III	Associate Administrator for Space Flight
Bryan D. O'Connor	Deputy Associate Administrator for Space Flight
Randy Brinkley	STS-61 Mission Director
Brewster Shaw, Jr.	Manager Space Shuttle Program

NASA Office of Space Communications

Charles T. Force	Associate Administrator for Space Communications
Eugene Ferrick	Director, Tracking & Data Relay Satellite Systems Division
Robert M. Hornstein	Director, Ground Networks Division

Goddard Space Flight Center

Dr. John M. Klineberg	Director
Vernon J. Weyers	Director of Flight Projects
Joseph H. Rothenberg	Associate Director Flight Projects-HST
Ann C. Merwerth	HST O&GS Project Manager
Frank Ceppolina	HST FS&S Project Manager
Dr. David S. Leckrone	HST Project Scientist
Dale L. Fahnestock	Director of Mission Operations and Data Systems Directorate

Kennedy Space Center

Robert L. Crippen	Director
Jay F. Honeycutt	Director, Shuttle Management and Operations
John T. Conway	Director, Payload Management and Operations
Joanne H. Morgan	Director, Payload Project Management

Johnson Space Center

Paul J. Weitz	Acting Director
Eugene F. Kranz	Director, Mission Operations
James M. Hefflin	STS-61 Flight Director
Jeffrey M. Handley	STS-61 Payload Officer
J.J. Conwell	STS-61 Payload Integration Manager

STS-61 Flight Crew

Richard O. Covey	Commander
Kenneth D. Bowersox	Pilot
Story F. Musgrave	Payload Commander
Tom D. Akers	Mission Specialist
Jeffrey A. Hoffman	Mission Specialist
Kathryn C. Thornton	Mission Specialist
Claude Nicollier	Mission Specialist

HST PROJECT COSTS

Servicing Mission Costs - HST

WFPC2	101.3
COSTAR	49.9
Other Flight Hardware	8.5
Simulators/Testing	72.3
Ops/Software Development	19.0
Total	251.0 Million

The portion attributable to correction of spherical aberration of the primary mirror is:

COSTAR	49.9
Mirror Characterization	2.9
Sustaining Engineering	1.4
WFPC2 Increases	23.8
Independent Verification	8.3
Total	86.3 Million (Included in $251 Million above)

Servicing Mission Costs - Shuttle

Nominal Shuttle Flight Costs	369.0
Augmentation for HST	9.0
Total	378.0 Million

Total STS -61 Mission Costs

Shuttle	378.0
HST	251.0
Total	629.0 Million

Total Project Costs through Fiscal Year 1993

Observatory and Instrument Development	**1544.9 Million**
Mission Operations and Data Analysis	**1425.5 Million**
TOTAL	2970.4 Million

HST ACRONYMS

COSTAR	Corrective Optics Space Telescope Axial Replacement
ECU	Electronics Control Unit
ESA	European Space Agency
EVA	Extra Vehicular Activity
FD	Flight Day
FSM	First Servicing Mission
FSS	Flight Support System
FOC	Faint Object Camera
FOS	Faint Object Spectrograph
GHRS	Goddard High Resolution Spectrograph
GSFC	Goddard Space Flight Center
HSP	High Speed Photometer
HST	Hubble Space Telescope
JSC	Johnson Space Center
KSC	Kennedy Space Center
NASA	National Aeronautics and Space Administration
ORI	Orbital Replacement Instrument
ORU	Orbital Replacement Unit
ORUC	Orbital Replacement Unit Carrier
OV	Orbital Verification
PCS	Pointing and Control Subsystem
RMS	Remote Manipulator System
RSU	Rate Sensor Unit
SA	Solar Array
SAC	Solar Array Carrier
SADE	Solar Array Drive Electronics
SMOV	Servicing Mission Operational Verification
STS	Space Transportation System

STScI	Space Telescope Science Institute
STOCC	Space Telescope Operations Control Center
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
WFPC1	Wide Field and Planetary Camera #1
WFPC2	Wide Field and Planetary Camera #2